Future Program for Studying Bulk Properties in High-Energy Nuclear Collisions

Nu Xu

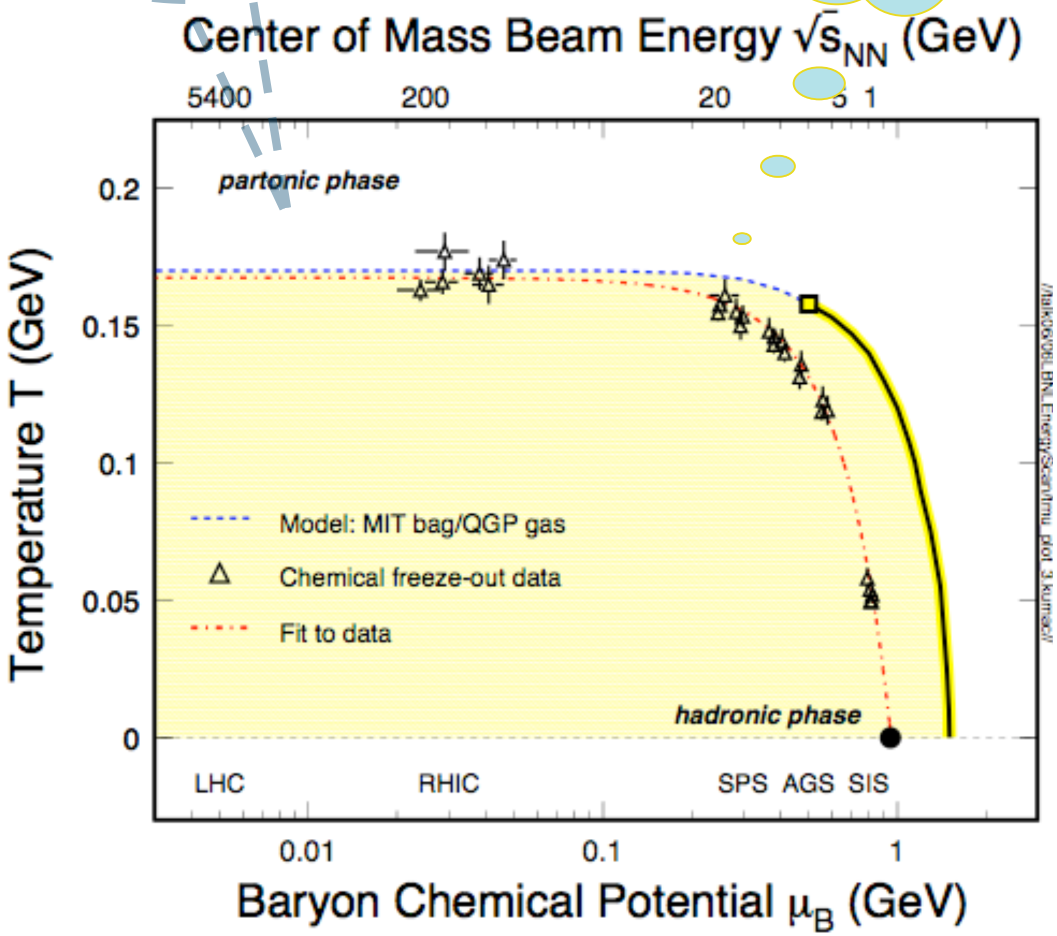
Outline

- What we have learned at 200GeV
- Baryon-rich physics
  - search for phase boundary (hadronic shore)
- Heavy flavor physics: STAR HFT
  - study the properties of the hot/dense medium ('sQGP') at RHIC

QCD Phase Diagram

deep partonic ocean

phase boundary?



RHIC results show:

1) **Jet-quenching** - hot and dense matter

2) **Strong elliptic flow v_2** - partonic collectivity

3) **Hadron yields thermal** - possible thermalization

Next Step:

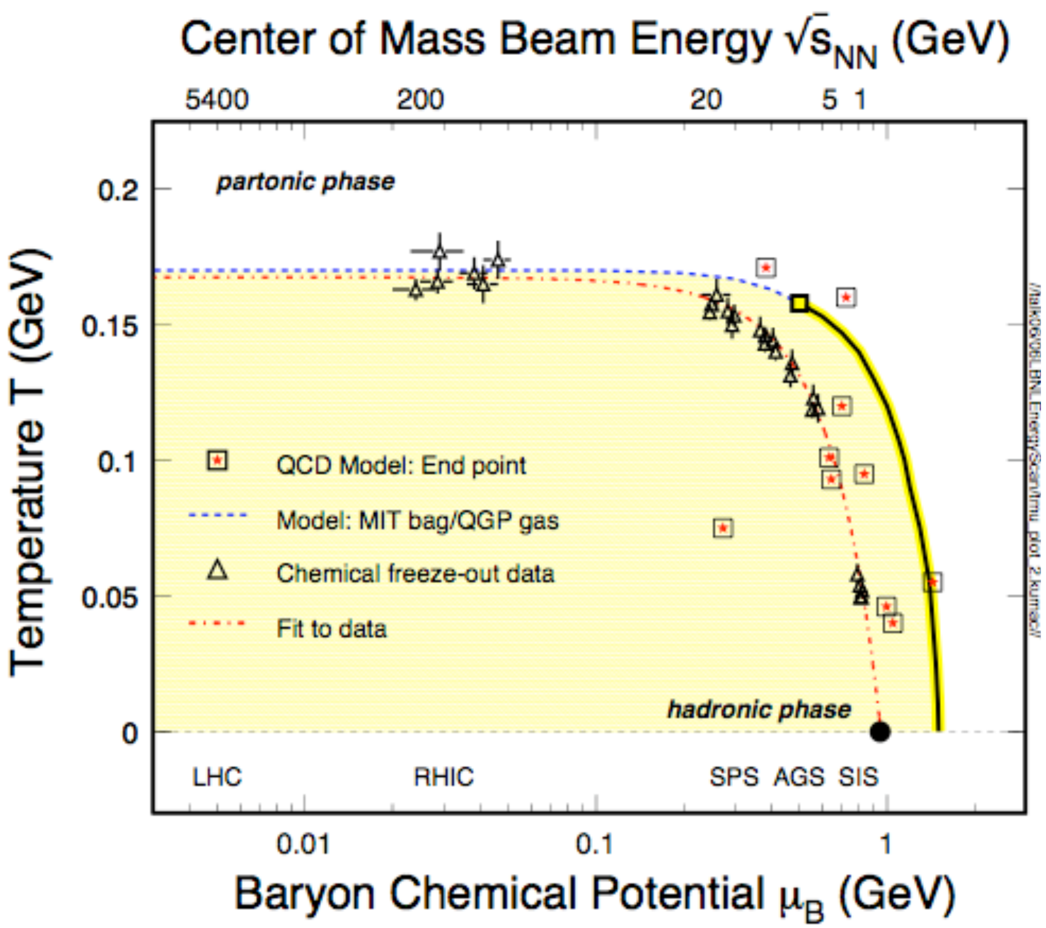
(a) Phase boundary?

(b) Thermalization?

Baryon-rich Physics:
Search for the Hadronic Shore

(2008 - …)

QCD Phase Diagram



Model predictions:

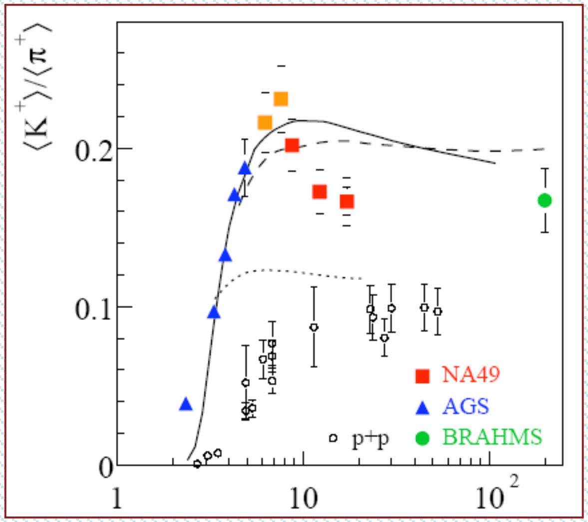
1) All 'end points' exist at μ_B > 0.1GeV

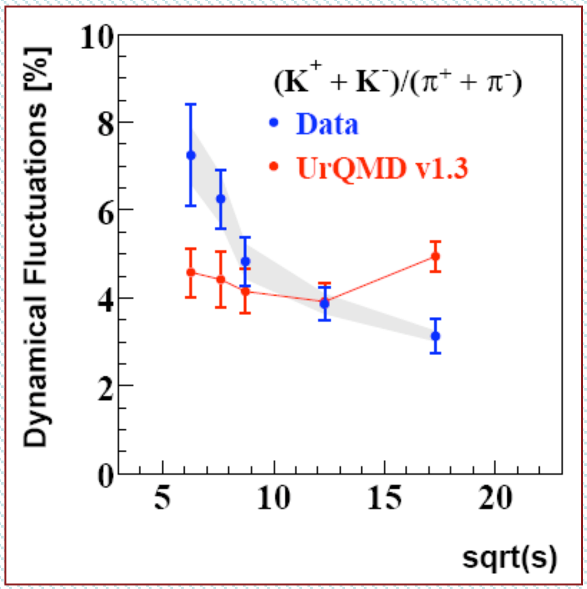
2) Most 'end points' exist at μ_B < 0.95GeV

3) Large uncertainties in the predictions. Data is important.

*M.A Stephanov, Prog. Theor. Phys. Suppl. **153**, 139(2004); Int. J. Mod. Phys. **A20**, 4387(05); hep-ph/0402115*

Early SPS Results





NA49 Experiment:

(1) The "horn" structure in $\langle K^+\rangle/\langle\pi^+\rangle$ ratios observed

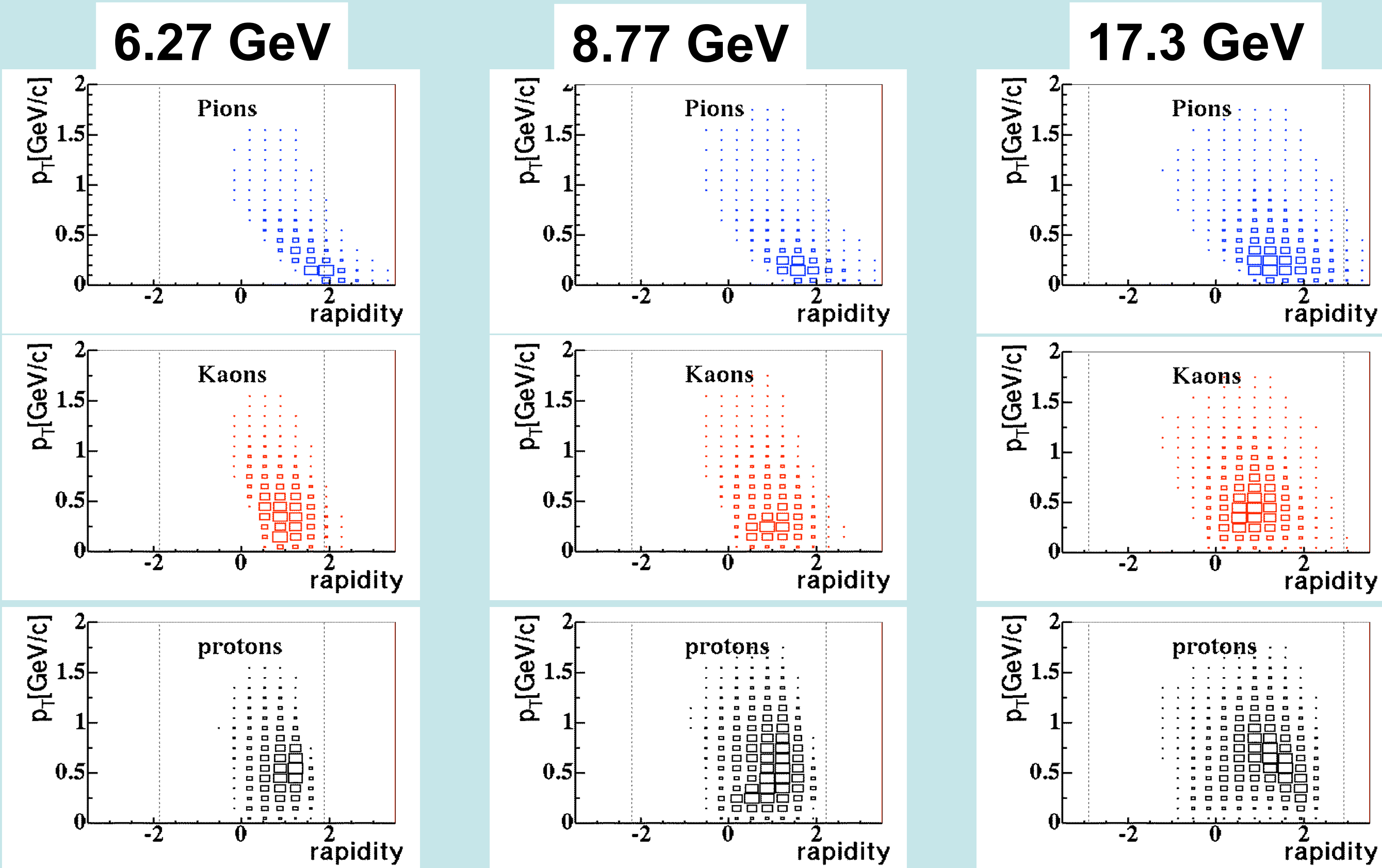
(2) Increased fluctuation signal at lower beam energies

$$\sigma^2_{dyn} = \sigma^2_{data} - \sigma^2_{mixed}$$

C. Blume (NA49), hep-ph/0505137

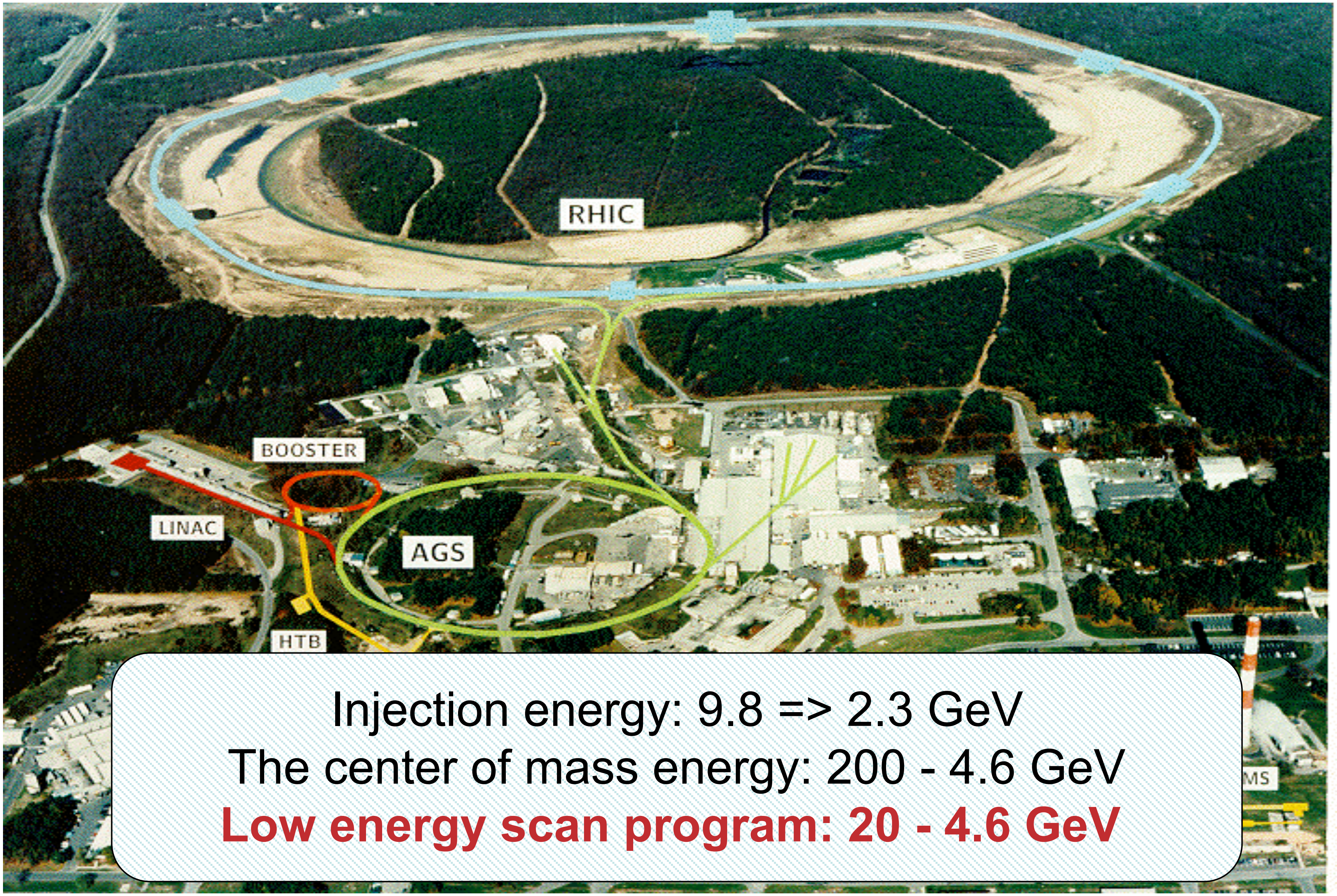
(3) Data suffer low statistics and large systematic uncertainties, due to acceptance and PID

Challenge: Changing Acceptance (NA49)



Slide from Christof Roland,
Correlations '05, MIT

RHIC

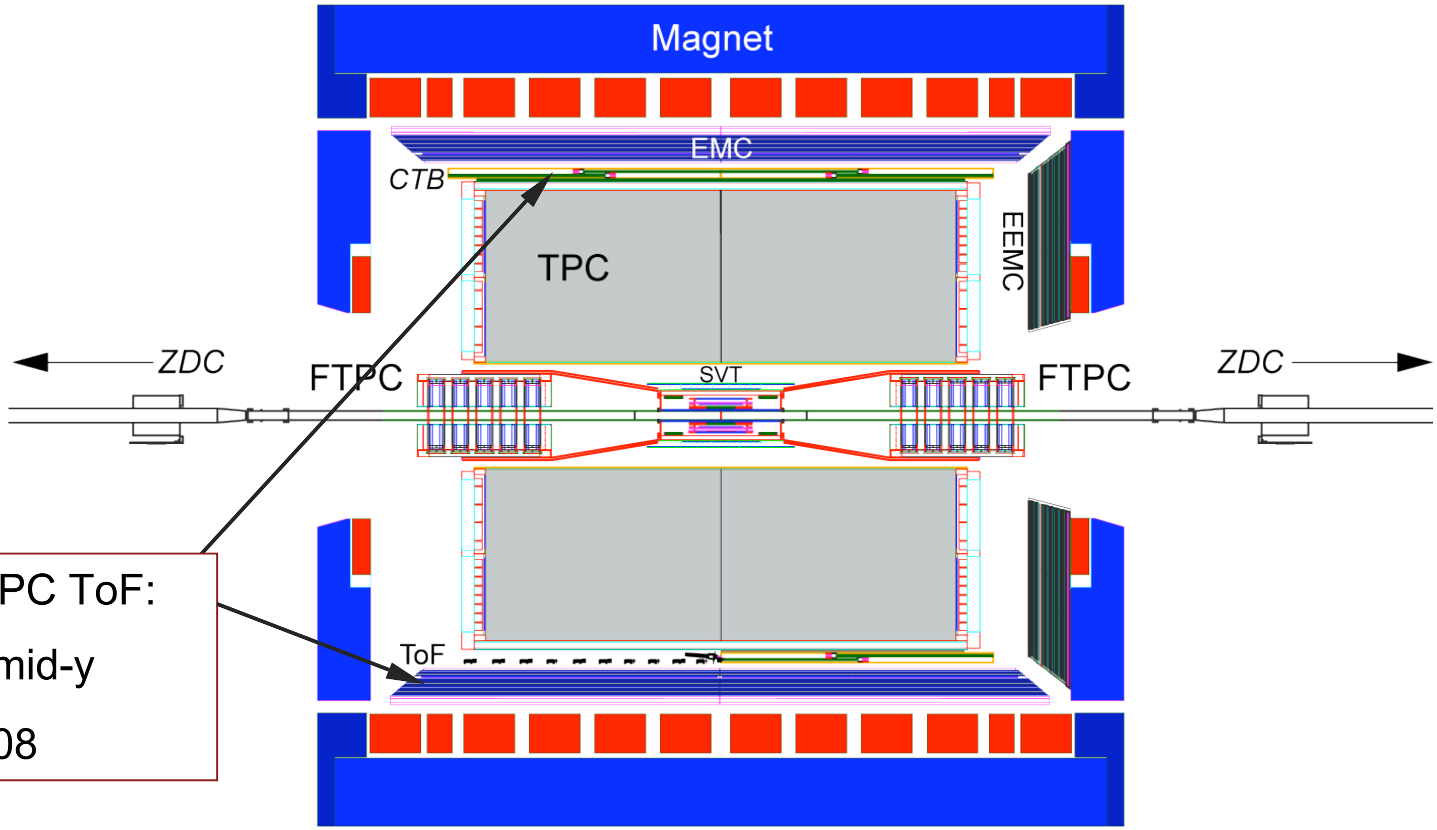


Injection energy: 9.8 => 2.3 GeV

The center of mass energy: 200 - 4.6 GeV

Low energy scan program: 20 - 4.6 GeV

The STAR Experiment



STAR MRPC ToF:

$\Delta\varphi=2\pi$ at mid-y

Finish: 2008

- Large acceptance: 2π coverage at mid-rapidity and low p_T
- Good PID: STAR MRPC ToF upgrade ready by FY2008

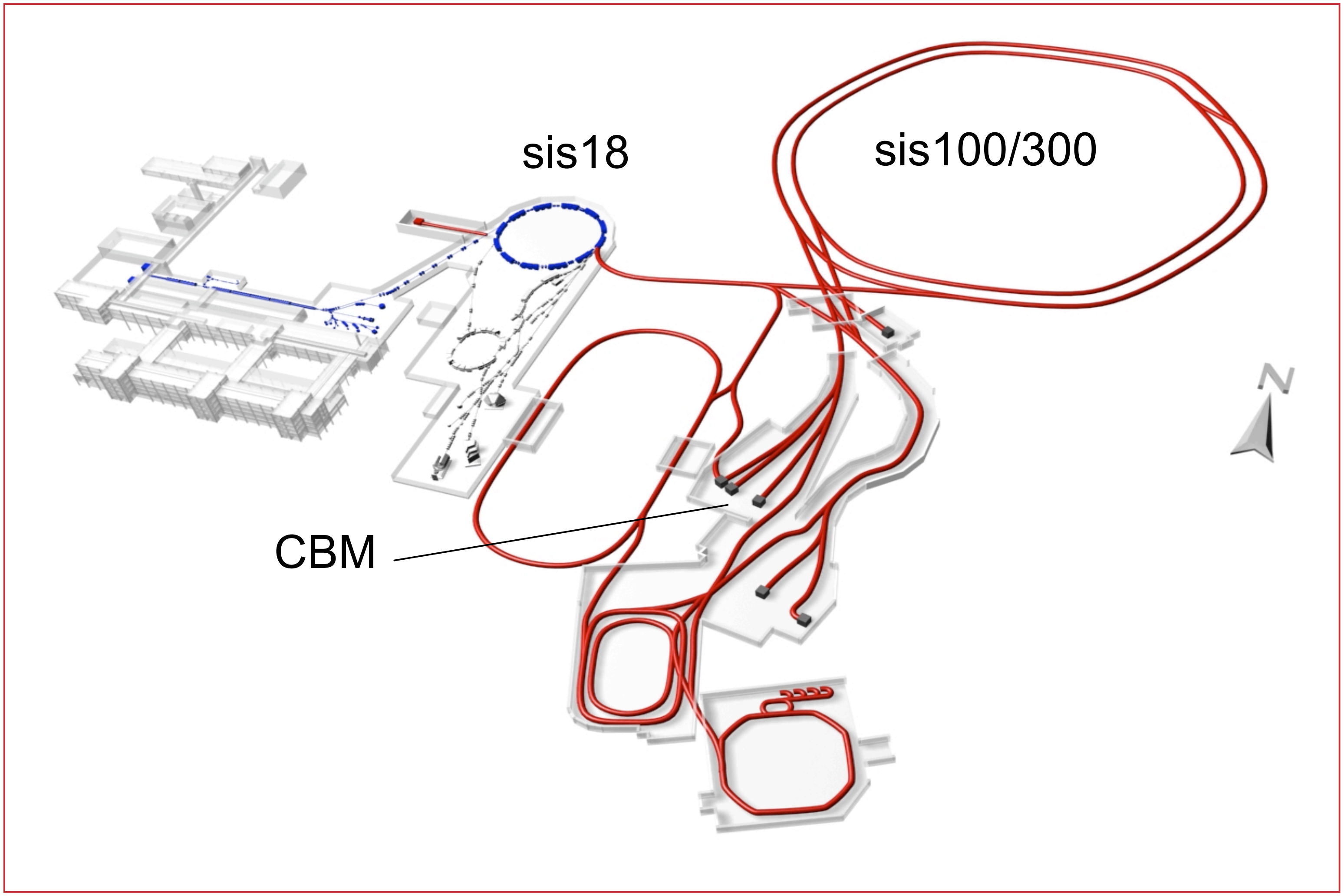
K, π ID up to p_T ~ 1.8 GeV/c and proton ID up to p_T ~ 4GeV/c

Beam-time Estimation at STAR

$E_{c.m.}$	μ_B	BBC Coin Rate	#of days/1M (1day=10 hr)	#of events needed	#of days of beam
4.6	570	3	9	5M	45
6.3	470	7	4	5M	20
7.6	410	13	2	5M	10
8.8	380	20	1.5	5M	7.5
12	300	54	0.5	5M	2.5
18	220	>100	0.25	5M	1.5
28	150	>100	0.25	5M	1.5

This is our fishing net: if the fish is bigger than the hole we will catch it.

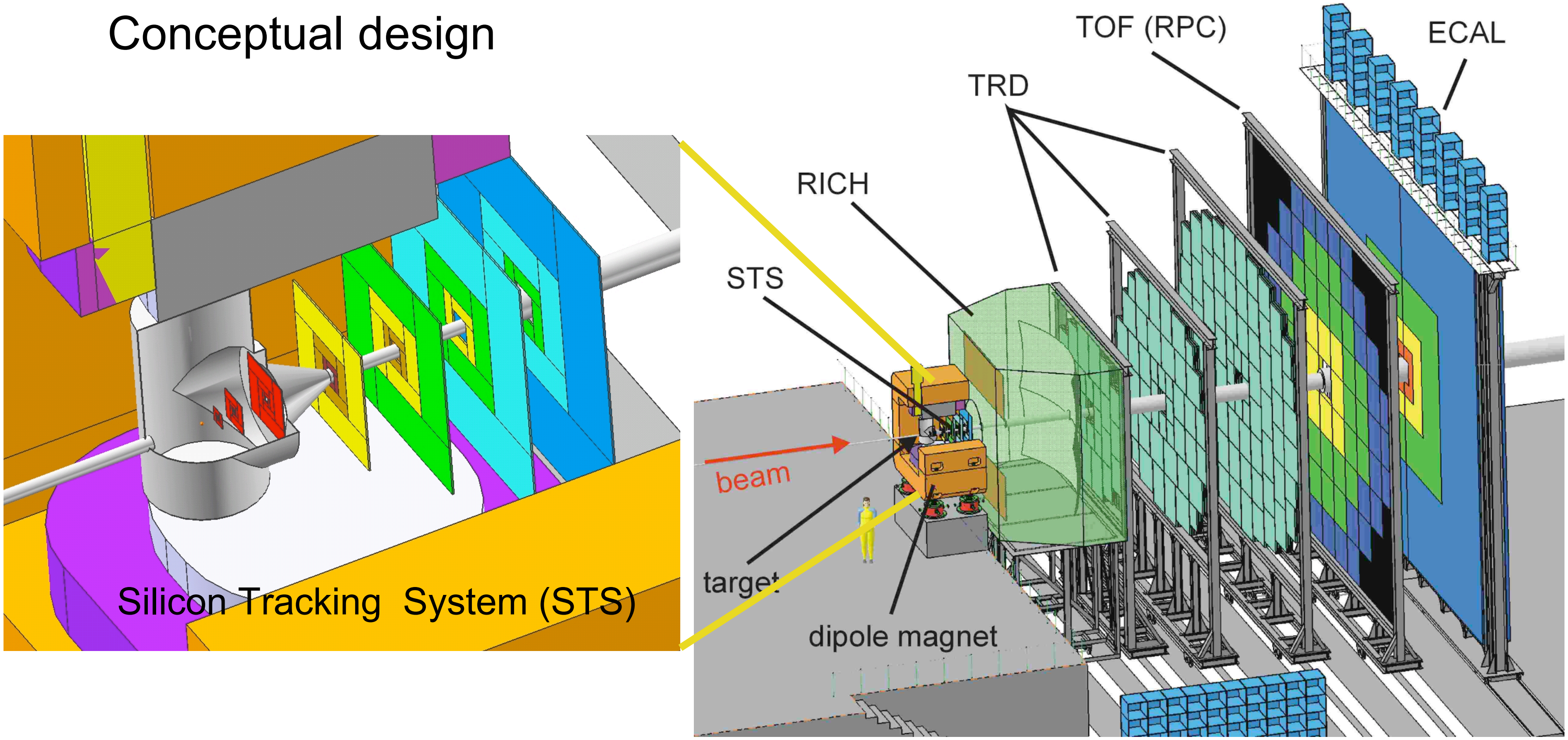
The International Facility for Antiproton and Ion Research



Heavy ion beams: 10^{10}/s ^{238}U 8.22 GeV // Ni 9.29 GeV

The Compressed Baryonic Matter (**CBM**) Experiment

Conceptual design



1) Radiation hard Silicon (pixel/strip) Tracking System
2) Electron detectors: RICH + TRD + ECAL (hadron suppression >10^4)
3) Charged hadron id: TOF-RPC
4) Neutral particles (γ, π, η) id: ECAL

Observables

- Spectra, v_2, and HBT of π, K, p, ϕ, Λ, Δ, Ξ, Ω, D, J/ψ
- Vector mesons: ρ, a_1, ϕ, …
- Fluctuations: $\langle N(h^{\pm}) \rangle$, $\langle N(K)/N(\pi) \rangle$, $\langle p_T \rangle$, σ_{dy}…
- Beam energy: RHIC **20 -- 4.6** GeV, starts in 2008
  FAIR **8.2 -- 2.1** GeV, starts in 2013

Step I: Disappearance of partonic activities

Step II: Fluctuation and vector meson production

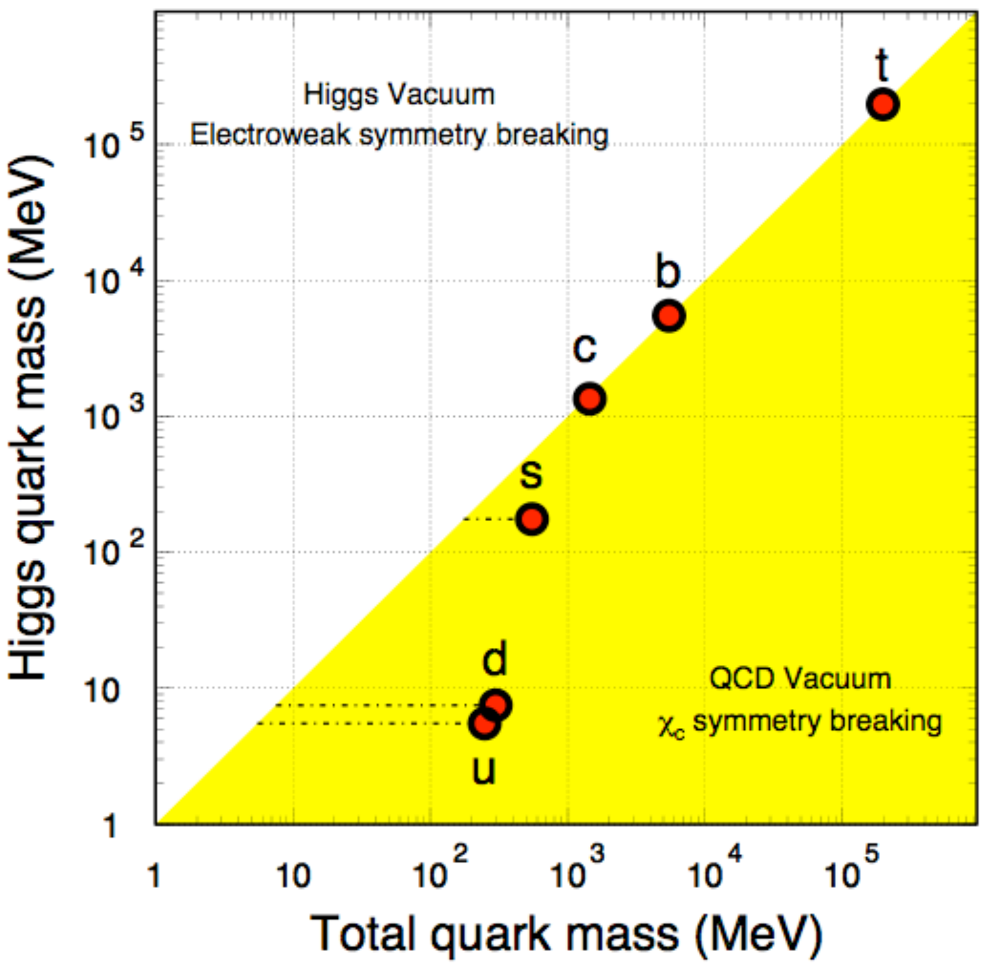
Theoretical efforts, predictions, are essential!

Studying 'sQGP' Properties at RHIC

The STAR Heavy Flavor Program

(2009 - ...)

Quark Mass



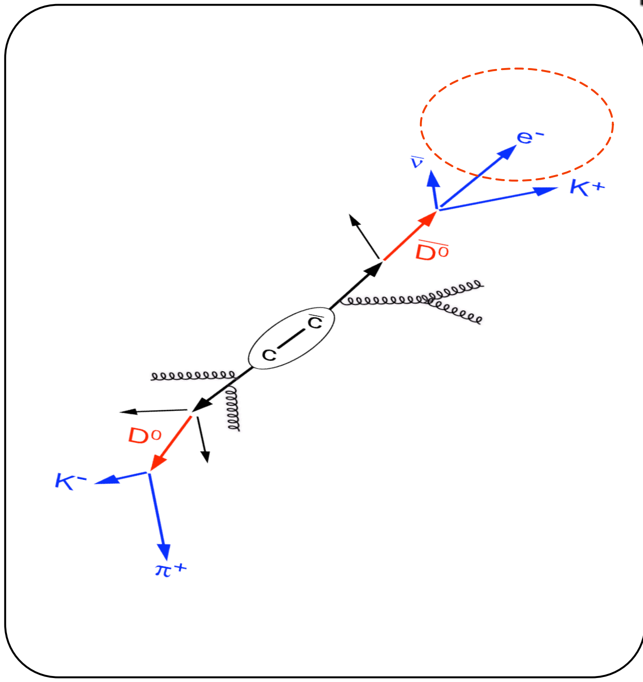
1) Higgs mass: electro-weak symmetry breaking (current quark mass).
2) Quark mass: Higgs + QCD (Chiral symmetry breaking) - constituent quark mass.

⇨ Strong interactions do not affect heavy-quark masses.

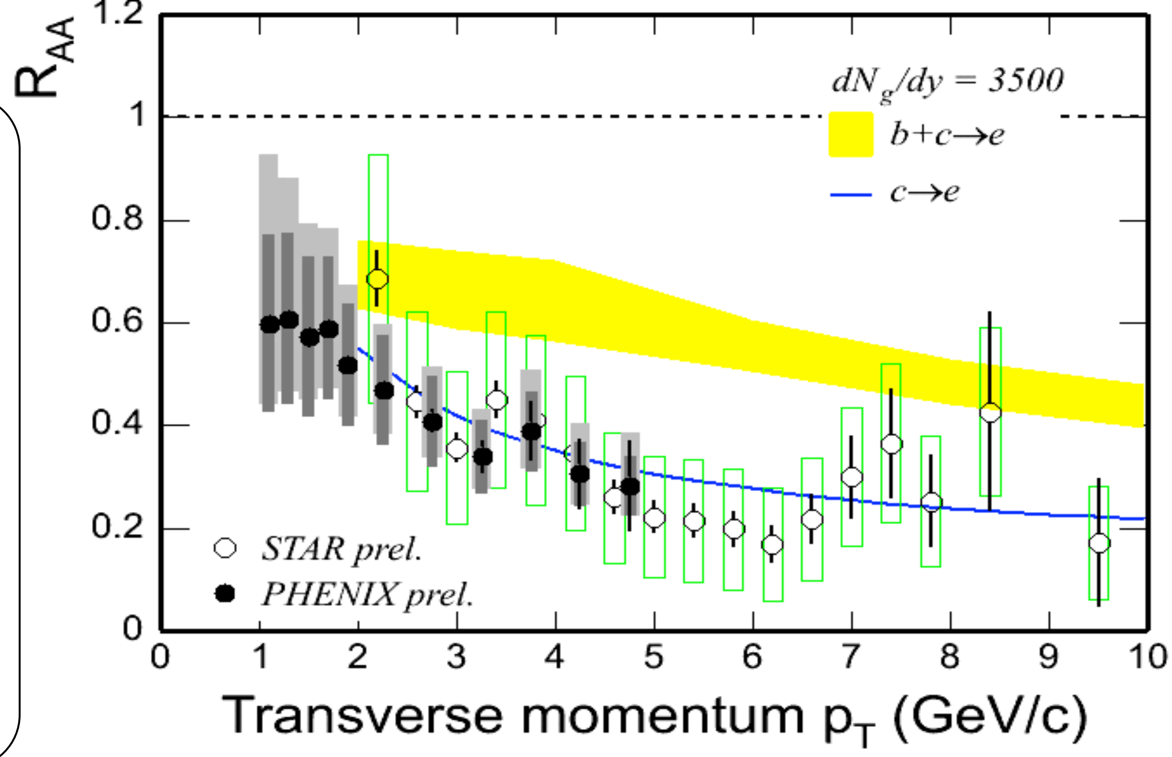
⇨ Important tool for studying properties of the hot/dense medium at RHIC.

⇨ Test pQCD predictions at RHIC.

Electrons: Mixture of c- & b- Dadrons

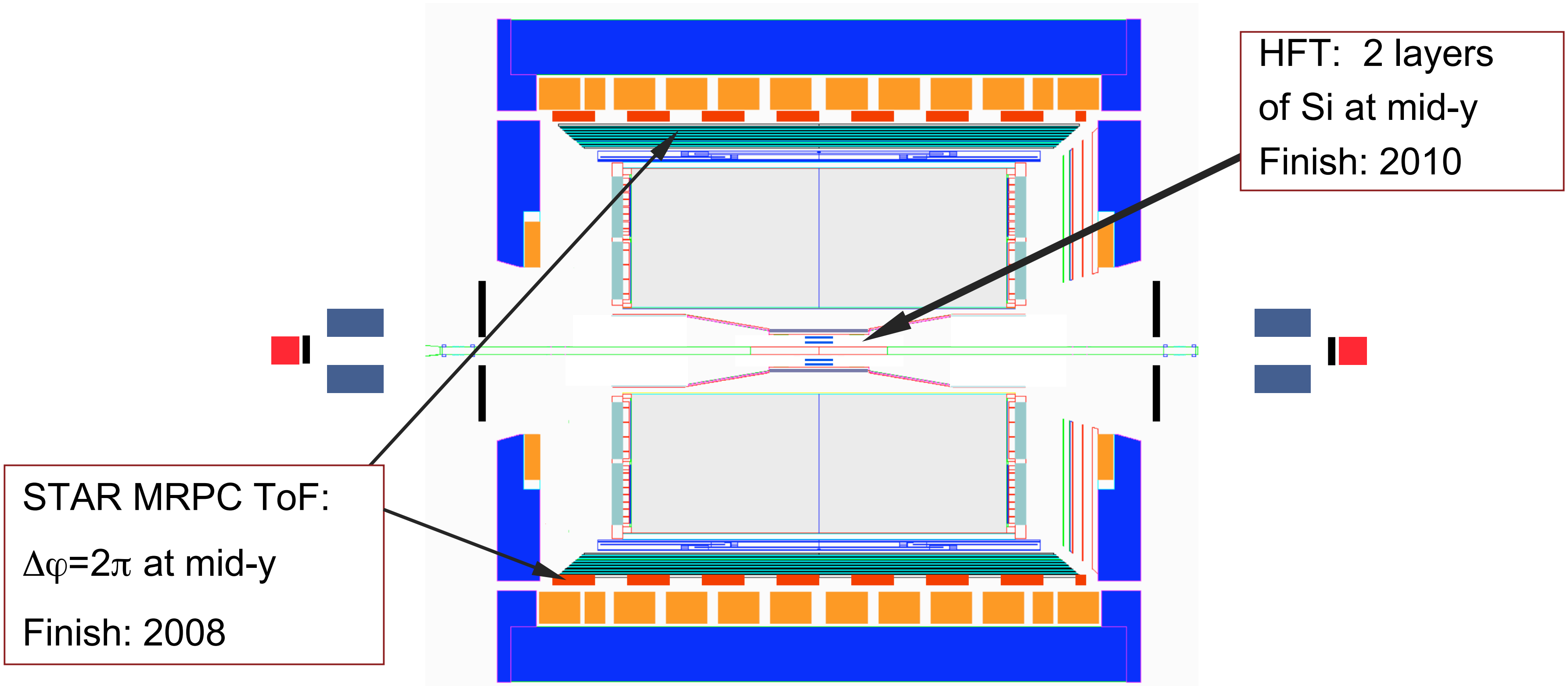


M. Djordjevic, et. al. nucl-th/0507019



Partonic energy loss - strongly interacting matter produced at RHIC!
Energy loss mechanism: under study *M. Gyulassy et al.*
Problem: isolation of Charm hadron contributions from Beauty-hadrons

The Heavy Flavor Tracker

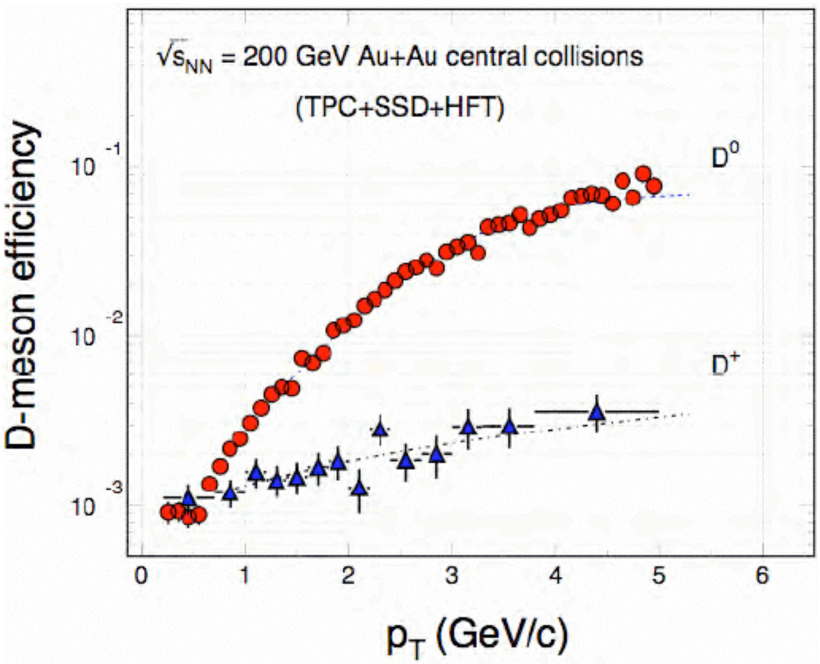


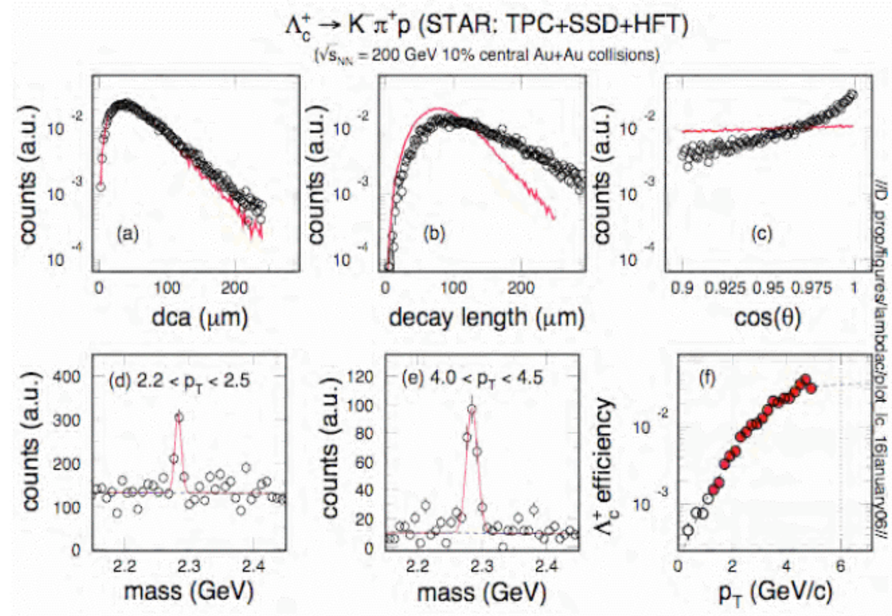
1) Precision tracking detector: ≤ 8 μm resolution at vertex

2) Topologically reconstructing charm-hadrons

3) Analyze charm-hadron **flow** (v_2) and **energy loss** ($\mathbf{R_{AA}}$)

Open-charm Hadron Reconstructions





1) D^0, D_s, D^+, Λ_c and their anti-particles can be reconstructed with the combination of the **HFT**+SSD+TOF+TPC.

2) Reasonable efficiencies at **low p_T** - important for flow analysis.

Rate Estimates - Spectra

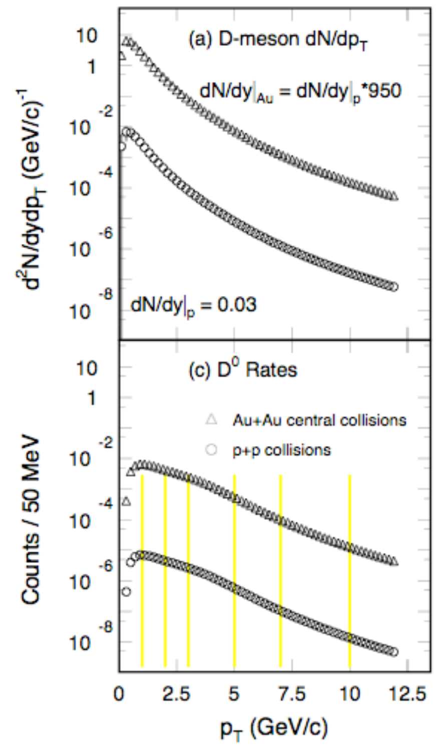
(a) dN/dp_T distributions for D-mesons.

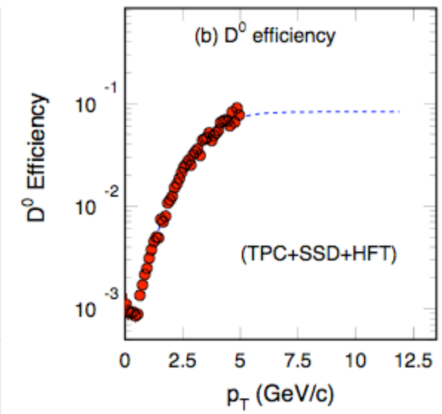
The integrated yield dN/dy = 0.03 as measured in p + p collisions at 200 GeV

----Phys. Rev. Lett. 94, 062301 (2005)

Scaled by $\langle N_{bin} \rangle$ = 950, corresponds to the top 10% central Au + Au collisions at RHIC.

(b) D^0 rates from p+p and top 10% central Au + Au collisions at 200 GeV.





p_T (GeV/c)	Δp_T (GeV/c)	# of Events (p + p)	# of Events 0-10% Au + Au (N_{bin} = 950)	# of Events 0-80% Au + Au (N_{bin} = 290)
1.0	0.5	44×10^6	0.45×10^6	1.75×10^6
2.0	0.5	70×10^6	0.45×10^6	1.75×10^6
3.5	1.0	70×10^6	0.45×10^6	1.75×10^6
5.5	1.0	350×10^6	0.75×10^6	3×10^6
7.5	1.0	1200×10^6	3.5×10^6	11×10^6
10.5	1.5	7500×10^6	9×10^6	30×10^6

Rate Estimates - v_2

(a) dN/dp_T distributions for D-mesons.

Scaled by $\langle N_{bin} \rangle = 290$, corresponds to the minimum bias Au + Au collisions at RHIC.

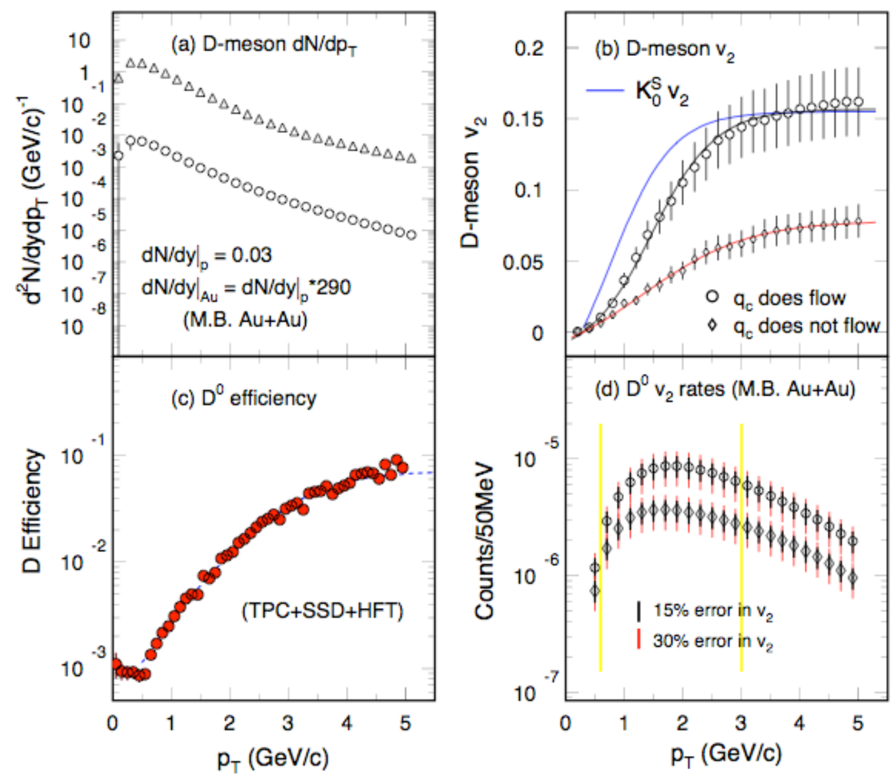
(b) Assumed v_2 distributions for D-mesons.

---- PLB 595, 202 (2004)

Error bars shown are from 15% systematic errors

(c) D^0 meson v_2 rates from minimum bias Au + Au collisions at 200 GeV.

The small and large error bars are for 15% and 30% systematic errors, respectively. For the v_2 analysis, 12 bins in φ are used.



p_T (GeV/c)	Δp_T (GeV/c)	# of Events q_c does flow	# of Events q_c does not flow
0.6	0.2	260×10^6	525×10^6
1.0	0.5	70×10^6	140×10^6
2.0	0.5	53×10^6	125×10^6
3.0	1.0	105×10^6	175×10^6
5.0	1.0	210×10^6	440×10^6

Summary II

(1) Test pQCD properties in hot and dense medium

- Charm- and Bottom-hadron spectra, R_{AA}, Charm correlations
- Sensitive and detailed study for partonic energy loss ⇨ `falsify pQCD, *a la Miklos Gyulassy'*
- Precision Charm cross section for J/ψ analysis - direct test de-confinement and Charm thermalization

(2) Test light-flavor thermalization

- Charm-hadron v_2 - partonic thermalization
- Di-lepton invariant mass distributions - χ_c symmetry

(3) Essential for spin heavy flavor physics

Theoretical efforts, predictions, are essential!

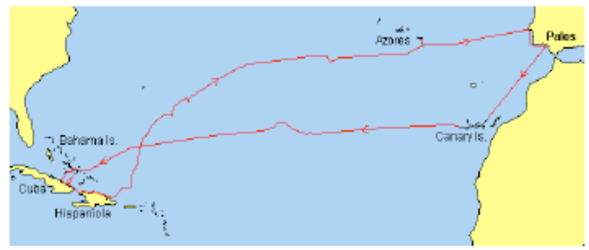
Columbus' Discovery and RHIC

Ed Shuryak: "One may have an absolutely correct theory and still make *accidental* discoveries…"

Columbus' Theory:

(1) world is not flat, $E_2 \Rightarrow S_3$

(2) if he goes west he should eventually come to India



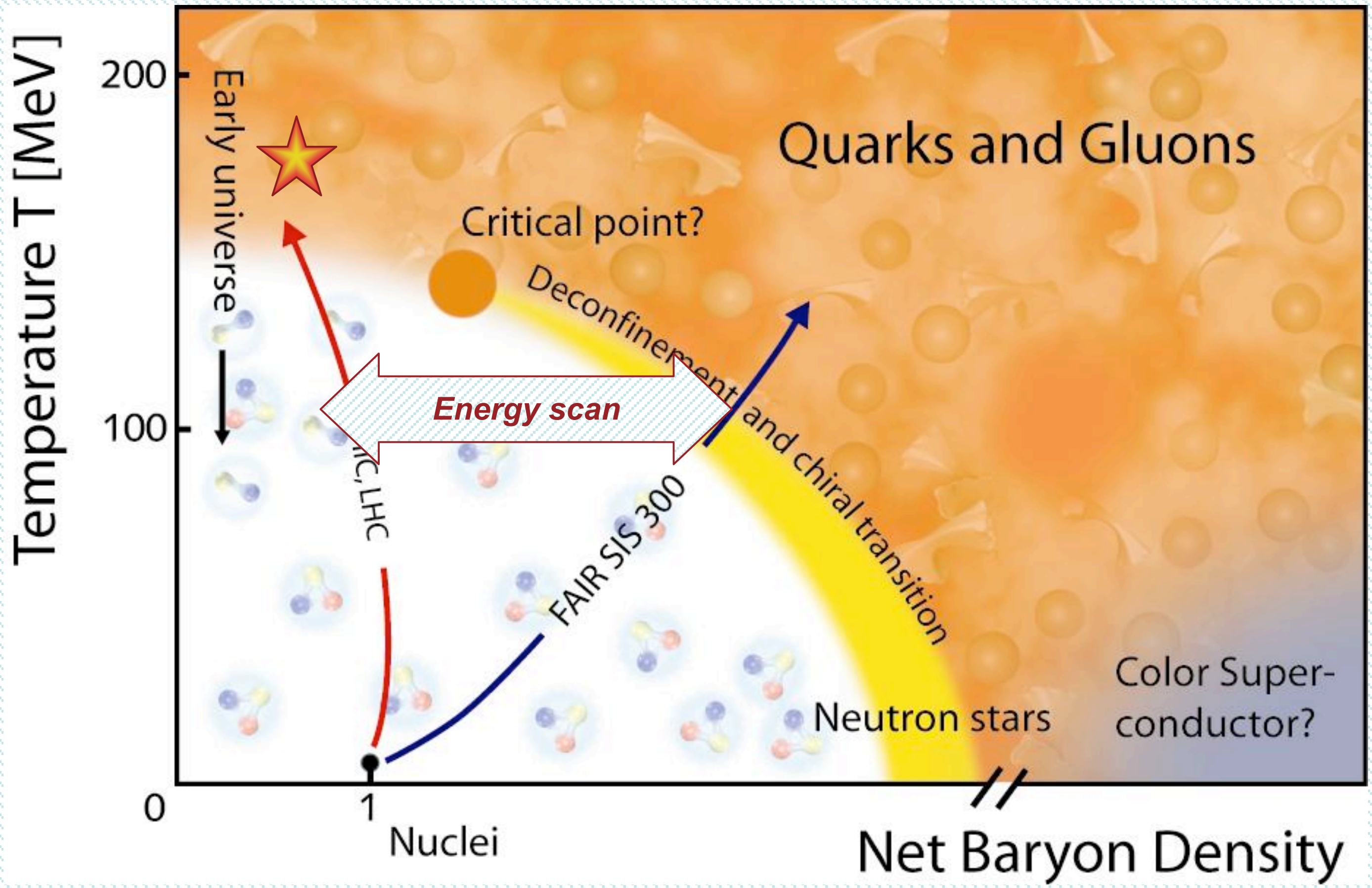
But he discovered something else was on the way…

We set out at RHIC we find wQGP. But 1000 experimentalists found something else on the way… the sQGP !

Gyulassy RBRC/BNL 12/16/04 8

RHIC's future and two important unknowns:

(1) **Boundary of the phases** and (2) **Properties of the 'sQGP'**



1) RHIC heavy-flavor program:
   - Study ***medium properties*** at RHIC
   - pQCD in hot and dense environment

2) Baryon-rich physics: ($RHIC_{BR}$ & FAIR CBM)
   - Search for the possible ***phase boundary*** and ***the tri-critical point***.
   - Chiral symmetry restoration